

Biology and Control of the White-Pine Weevil, *Pissodes strobi* Peck

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AN ADULT WEEVIL ON A BUD CLUSTER OF WHITE PINE

The feeding punctures show on the buds

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BIOLOGY AND CONTROL OF THE WHITE-PINE WEEVIL, PISSODES STROBI PECK

SAMUEL A. GRAHAM

The white-pine weevil is one of the most destructive pests of the eastern white pine. In some localities the planting of this tree has been practically abandoned because of its ravages, and throughout the range of its host tree it has been a large factor in discouraging private reforestation of waste lands. It is therefore an important forest insect, not only because of the actual damage that it does, but also because of the bad psychological effect which its presence produces upon owners of forest properties where white pine is an important tree.

This weevil was early brought to the attention of entomologists, and evidently it has always been an important forest insect throughout the range of the eastern white pine. The earliest observers of the insect found that to a certain degree it was controlled by several parasites. Peck (1817) states that "our forests would scarce produce a single mast" were it not for this controlling factor. Today, although the demand for masts is a small item in the white-pine trade, the merchantable value of the timber still depends on the straightness of the main stem, and any crook or deformity such as that caused by the weevil reduces the value of the timber.

Peck described this weevil in 1817 and made a few notes on its life history. Since that time it has been studied by a number of entomologists, each of whom has contributed more or less to the knowledge of the species. Unfortunately, the white-pine weevil has been confused with some of its close relatives. This has led to many misleading, and even incorrect, statements concerning its life history and habits. One of the purposes, therefore, of the experiments upon which this paper is based, was to determine the true life cycle and habits of the insect as distinguished from those of its close relatives. The second and more important purpose was to find, if possible, some practical methods of controlling the weevil.

The study was begun in 1915 as a thesis problem under the direction of Professor Glenn W. Herrick, of Cornell University, and the greater part of the biological data included in this bulletin were collected at Ithaca during the summer of 1915. During 1916, most of these observations were checked and further work on the control problem was conducted at Ithaca and also on the Luther Forest Preserve near Saratoga Springs, New York, for the Department of Forestry at Cornell University. In 1917 and 1918, further studies were carried on in Isanti County and other localities in Minnesota, for the Minnesota Agricultural Experiment Station. Some of the results of the Minnesota studies have appeared in an article in the *Journal of Forestry* (Graham, 1918). Thus there has been opportunity to check results in several widely separated localities. In this bulletin an attempt is made to collect all of these data into a comprehensive whole.

INJURIOUS HABITS

CHARACTER OF THE INJURY

The injury done by the white-pine weevil is confined to the terminal part of sapling pines. The lateral branches are seldom injured. From a point just below the terminal bud cluster, the larvae work downward in the inner bark and girdle the shoot as they progress. The injury



FIGURE 1. LEADING SHOOT KILLED BY WHITE-PINE WEEVILS

usually extends to a point below the topmost whorl of branches only, but many instances have been observed in which the tree has been killed below the second, or even the third, whorl from the top (figure 1). When the leader is destroyed in this way, the laterals in the topmost living whorl of branches compete for supremacy. In some instances one lateral succeeds in overtopping the others and takes the lead, and in such a case the tree either outgrows the injury or a bayonet trunk results. Sometimes, however, two or more laterals may take the lead, and produce a forked tree. In some cases weevil injury may render the trees commercially valueless.

Even where a single lateral takes the place of the killed leader and the tree outgrows completely the weevil injury, there is always a loss in height growth. If the leader is not killed below the first whorl, this loss is only the difference between the length of the terminal and the length of the lateral that takes its place. This difference varies in proportion

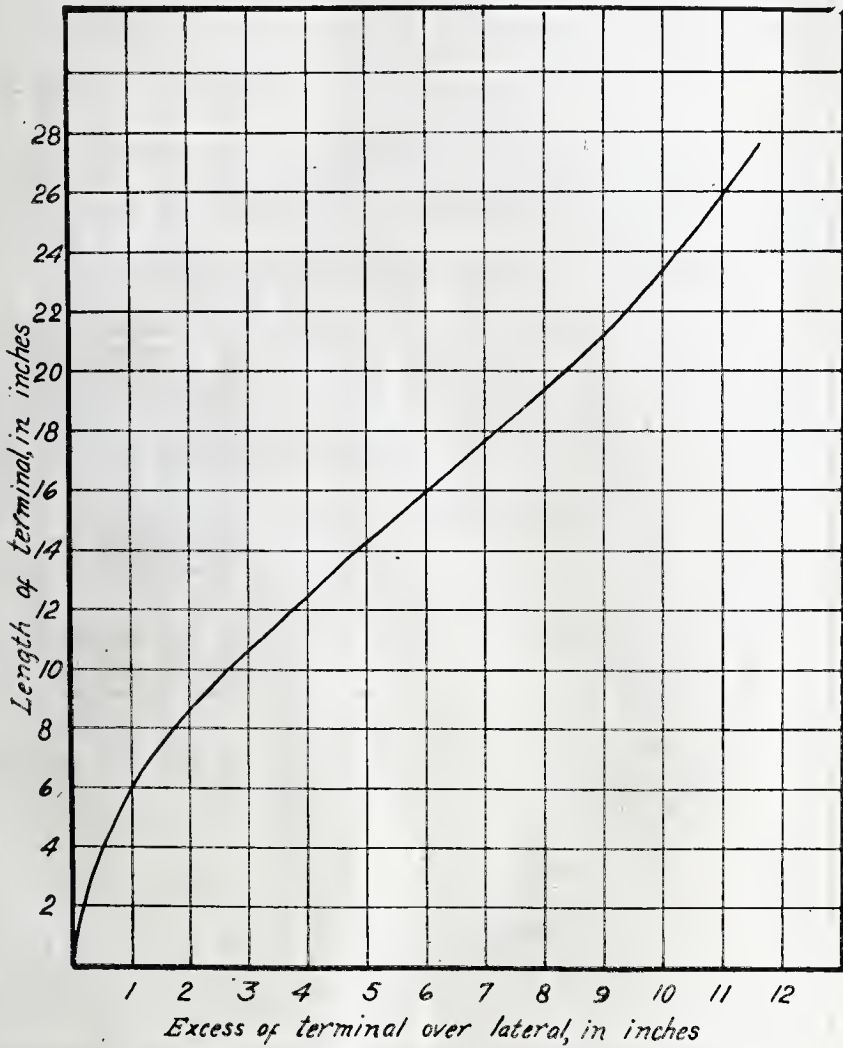


FIGURE 2. RELATION BETWEEN THE LENGTH OF THE LEADING SHOOT (TERMINAL), AND THE AVERAGE EXCESS OF THE LEADER OVER THE CORRESPONDING LATERAL

to the rate of height growth. The relation between the length of the leading shoot and the average excess of the length of the leader over that of the corresponding lateral, is shown in figure 2. If, however, the weevil girdles the tree below the topmost whorl, the loss in height is equal to the difference between the length of the main stem above the topmost living whorl and the length of the lateral that assumes the lead. The average loss per tree, in feet, at different densities of the stand, is shown

in figure 3. The number of trees per acre as indicated on this graph, is the original number before any thinning or crowding-out has taken place.

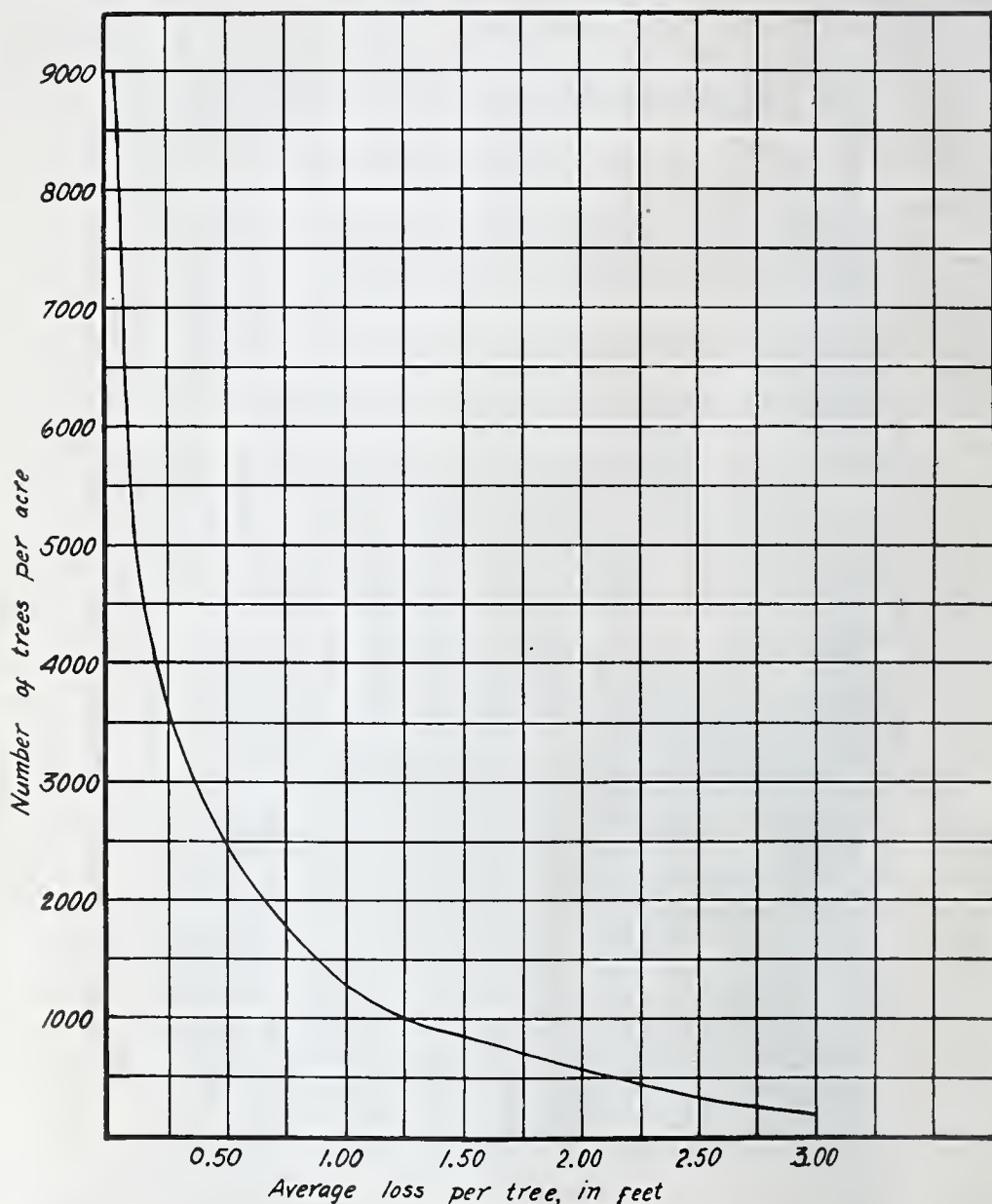


FIGURE 3. AVERAGE LOSS IN HEIGHT GROWTH PER TREE, IN FEET, RESULTING FROM WEEVIL ATTACK AT DIFFERENT DENSITIES

It has been estimated that from 70 to 90 per cent of all the white pines in New York and New England have been weeviled before they have reached the age of fifteen years. In Minnesota this percentage is somewhat lower. Unless steps are taken either to reduce this injury to the minimum or to assist the trees in outgrowing the resultant deformity, a crop of crooked, forked trees, of very little commercial value, will result.

In addition to the direct damage caused by weevil attack, there are other secondary injuries that are of considerable importance. One of these is snow breakage. The irregular, dense growth of weeviled trees holds the snow to a much greater degree than does the normal straight pine. An extreme example of combined weevil and snow injury was observed not far from the Cornell University campus, in a group of trees located in a hollow where heavy snows collect. These trees were broken beyond any hope of recovery, and were little more than sprawling shrubs, barely able to keep alive.

HOST TREES

The eastern white pine (*Pinus strobus*) is the favorite host of the white-pine weevil. However, the insect sometimes attacks other species of pine and some species of spruce. Scotch pine (*Pinus sylvestris*), pitch pine (*Pinus rigida*), and jack pine (*Pinus Banksiana*) are frequently attacked when growing in mixture with, or near, young white pines. Red pine (*Pinus resinosa*) is much more resistant but is occasionally injured. Norway spruce (*Picea excelsa*) is very susceptible and is second to white pine as a favored host of this insect. Other species that have been reported as somewhat susceptible are Japanese pine (*Pinus densiflora*) (Peirson, 1922), Himalayan cedar (*Cedrus deodara*) (Currie, 1905), red spruce (*Picea rubra*) (Hopkins, 1911), balsam fir (*Abies balsamea*) (Packard, 1890), and eastern hemlock (*Tsuga canadensis*) (Packard, 1890). It is possible that some of these earlier records may have resulted from the confusion of other species of *Pissodes* with the white-pine weevil. Packard, in his writings, evidently confused several species of *Pissodes*, and, as his records of hemlock and balsam fir as host trees of the white-pine weevil have not been verified by recent workers, it is possible that these two species should not be included as host trees of this insect.

Since white pine is not only the favorite host of the white-pine weevil but is also the most important of the susceptible species as a timber tree, the experiments in both New York and Minnesota have been confined almost entirely to the activities of the weevil on this tree.

RELATION OF INJURY TO AGE AND HEIGHT OF TREE

The first attack of the white-pine weevil usually occurs when the trees are from five to seven years old and from two to three feet in height. The infestation is generally rather light during the first year or so, but it steadily increases, reaching the maximum when the trees are from twelve to eighteen years old. From then on, the infestation declines rapidly in intensity, and it practically ceases to be economically important when the trees are from twenty-five to thirty years old.

The rate of infestation appears to be correlated with the rate of growth of the trees, as is shown later in this bulletin; but there seems to be also some connection between the height of the trees and weevil injury (figure 4). The weevil ordinarily ceases to work on the trees after they have reached a height of from twenty to thirty feet. No entirely satisfactory explanation of this has been offered. It has often been assumed that insects which work only on low trees are habitually low fliers, and that when a tree attains a certain height it is beyond their reach. This may be the true explanation; but it is equally probable that the changing eco-

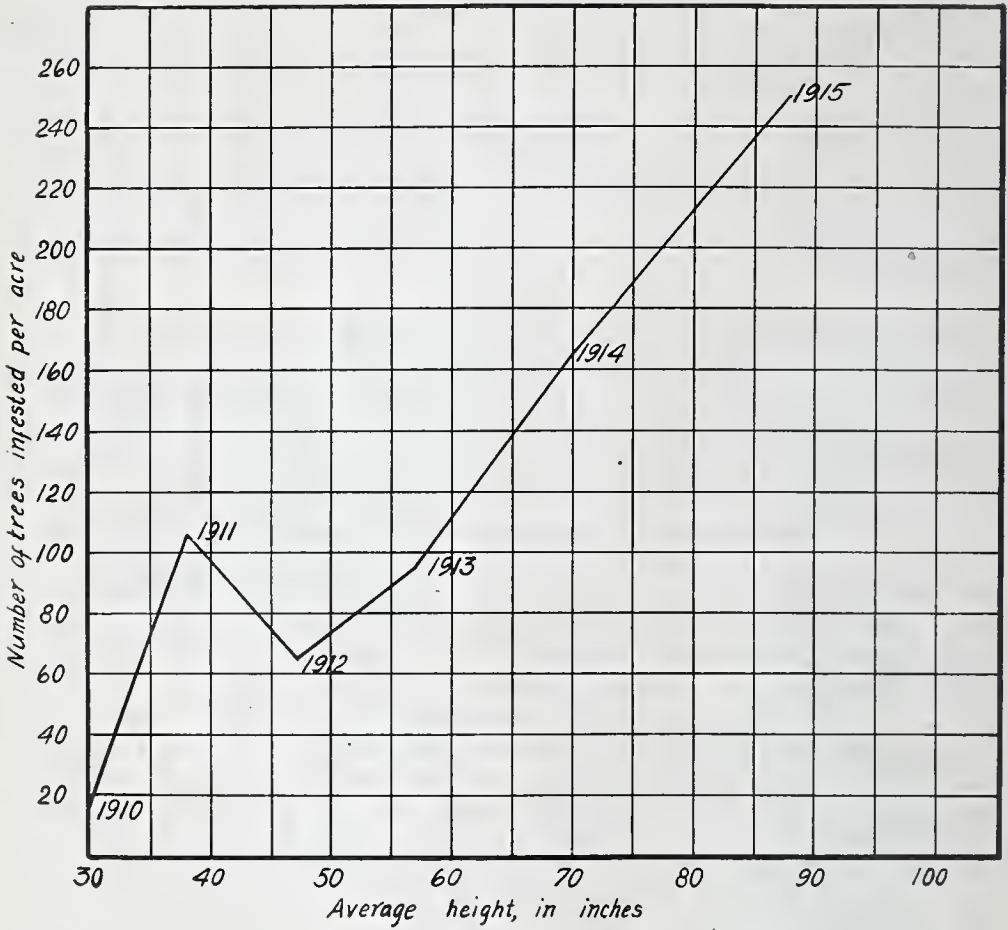


FIGURE 4 INCREASE OF THE INTENSITY OF WEEVIL INFESTATION WITH HEIGHT GROWTH, FROM 1910 TO 1915

This graph was constructed from data collected on a series of sapling plots on the Luther Forest Preserve. In 1910 the trees on these plots averaged seven years of age, two years after weeviling began

logical conditions which take place conjointly with the development of the stand, may offer a more adequate explanation.

In this study it was impossible to follow through, from year to year, the development of the young white-pine stands that were examined. At the conclusion of the investigation, the trees on the plots had not yet passed beyond the period of greatest susceptibility, and therefore the curve represented in figure 4 is incomplete. This figure does, however, show that the rate of infestation increased rapidly during the period from 1910 to 1915, as the trees grew from two and one-half to seven feet in height.

RELATION OF INJURY TO CROWN CLASS AND RATE OF GROWTH

From the foregoing section it may be inferred that the weevil has a decided preference for trees of certain ages and heights. Observations have shown that even during the highly susceptible age the weevil shows a preference for certain trees. It seems to choose the most thrifty and rapidly growing trees in the stand.

In even-aged stands growing normally, the most rapidly growing trees are in the dominant and co-dominant crown classes. The distribution, according to crown class, of trees weeviled in 1916, is shown in table 1, wherein it is seen that the weevil injury is confined for the most part to these two classes. Although these data were collected from sample plots in New York, they are typical of the conditions existing in all localities where the white-pine weevil has been studied.

TABLE 1. DISTRIBUTION OF TREES WEEVILED PER ACRE IN 1916, ACCORDING TO CROWN CLASS

Plot no.	Average height growth in 1915 (inches)	Number of trees weeviled in 1916 in the several crown classes			
		Dominant	Co-dominant	Intermediate	Suppressed
2.....	20	128	48	16	0
3.....	20	176	64	0	0
4.....	22	176	48	0	0
5.....	24	192	0	0	0
6.....	15	112	0	0	0
7.....	15	528	64	0	0
8.....	14	240	32	0	0
9.....	18	384	96	0	0
10.....	14	160	0	0	0
11.....	15	144	0	0	0
12.....	16	192	16	0	0
Average.....	17.5	221	33.5	1.5	0

The crown class of a tree is indicative of two things: first, it indicates the position and size of the crown, relative to other trees in the stand; and secondly, in even-aged stands it is an indication of the rate of growth. The plots used as a basis for table 1 were all located in even-aged pure stands of young white pine, in which the dominant trees were, for the most part, rapidly growing trees. The data prove, therefore, that the dominant rapidly growing trees are the ones most attractive to the weevil. However, since the dominant trees were also the most vigorous, there is nothing to show whether it was the superior height or the rapid growth of the trees which determined their susceptibility.

It has been assumed by Peirson (1922) that the height of the tree is the more important factor. This hypothesis is in accord with Peirson's assumption that the beetles probably fly to the terminal shoots of the pines, and, in flying over a stand, select the tallest trees. In the work on which this paper is based, however, no evidence has been found that the beetles reach the terminals by flying. If they creep up the trees from the ground — and there is direct evidence that this does occur (pages 11-12) — it is difficult to see how superior height alone could be an attraction to the weevils.

In the field observations in New York, nothing was found which would prove that the weevil prefers the tallest trees if those trees are not also the most rapidly growing trees in the stand. There was, on the other

hand, no small amount of evidence in proof of the contention that the weevil chooses the most rapidly growing trees, irrespective of their height. In stands where the trees were of unequal ages and heights, the weevil chose for attack the younger and shorter trees whenever these were growing more rapidly than the older and taller trees.

Field observations as to this preference of the weevil were further supported by an experiment at Ithaca in which four saplings were inclosed in a large cage. One of the trees was shorter than the others but was growing more rapidly. Six pairs of weevils were introduced into this cage on May 3, 1915, and left free to select the tree best suited to their needs. On the day following their introduction, four of the six females began ovipositing on the small, rapidly growing tree. No other tree in the cage was attacked during the entire season.

From the evidence at hand, it would appear that, in determining the trees suitable for weevil attack, rate of growth is more important than superior height. But, since rapid growth and superior height go together, the dominant trees in the stand are found to be the ones most often attacked.

This habit of stunting the best trees causes more damage than the mere loss of so much height growth in the infested trees. It interferes with the normal development of the whole stand: for, by its reducing the height growth of the most vigorous trees, the natural process of thinning is retarded; backward trees, instead of being crowded out, overtake the leaders; the rate of growth for the stand, as a whole, is reduced; and, unless artificial thinnings are made, stagnation is likely to result.

LIFE HISTORY AND HABITS

ACTIVITIES OF THE OLD ADULTS

In 1915, the first adults were observed on April 26 and the next day they were seen to be ovipositing. Because of seasonal variations from year to year and because of the variations between different latitudes, a description of the general condition of arboreal vegetation at the time of emergence of the weevils from hibernation gives a more reliable indication of the emergence time than does a date alone. At the time when the weevils first appeared in 1915, the pine buds had just begun to swell. Of the deciduous trees, only the cherries were beginning to put forth leaves. The American elms had begun to set fruit, and the shadbush and the aspens were in full bloom. The oaks and the hickories showed scarcely any sign of activity.

The weevils, as soon as they appear, begin feeding on the buds of the white pine. It is usually the terminal cluster of the leading shoot that is thus attacked. The weevils chew holes in the buds, and sometimes make cavities of considerable size. This injury, in itself, is important; but it is overshadowed by the later and much more serious damage caused by the larvae. Sometimes, to vary their diet a little, the adults feed on the inner bark of the terminal shoot.

There is still some question as to the manner in which the adult weevils reach the leading shoots of the trees. Peirson (1922) assumes that they fly over the young pines and alight on the tallest terminals. This assumption appears to be open to some question, inasmuch as the weevil has

seldom been observed in flight. Only once in the course of these investigations has it been observed on the wing. This one occasion was in mid-afternoon of a warm day in the early spring of 1916. On that day, many weevils were flying. They were strong fliers, and when in the air their movements were similar to those of such bark beetles as *Hylurgops*. This unusual occurrence suggests the possibility of a short period of flight during early spring, whereby the weevil becomes widely disseminated, followed by a period when it seldom if ever takes wing.



FIGURE 5. ADULT WHITE-PINE WEEVIL

During the spring of 1916 an experiment was conducted to determine, if possible, how the adult weevils reach the leading terminal. Two bands of tree tanglefoot, one just above the ground and the other at the base of the leading shoot, were placed around the stems of forty trees in a stand of young white pine that had been heavily infested by the weevil in 1915. These bands were applied just before the adults began to emerge from hibernation. As soon as the weevils began to emerge, about two hundred were collected and liberated on the ground in the center of the plot. This number of weevils, added to the number already present, insured a heavy infestation.

With this arrangement of tanglefoot bands, it was certain that any weevils found on the terminal of a banded tree had not crawled up the tree. Any that were caught in the upper band must have alighted on a side branch, and any that were caught in or found below the lower band must have crawled up from the ground. During the entire season, no weevils were caught in any of the bands. Many weevils, however, were

found collected below the lower bands. Apparently they were attempting to crawl up the trunks in order to reach the terminals.

Up to June 15, none of the banded trees were infested. By July 21, however, three weeviled shoots were found on the plot. It is possible that the weevils may have flown to the tips; but it is more likely that, during a cold rainy period in the latter part of June, the tanglefoot may have become glazed sufficiently to permit its being crossed by the weevils.



FIGURE 6. EGGS AND YOUNG LARVAE OF THE WHITE-PINE WEEVIL

Of the thirty unbanded trees on this plot, eleven were weeviled — an unusually large proportion for a single season. From this experiment it appears probable that, although the white-pine weevil is, under certain conditions, a good flier, it usually reaches the terminal shoot by creeping up the trunk of the tree.

In the spring, after having fed on the trees for a day or two, the beetles mate. During the entire oviposition period they are usually found in pairs, a male nearly always being found wherever a female is ovipositing. It appears, however, that they occasionally mate in the autumn previous to the period of oviposition. The possibility of this was first indicated by an occurrence in one of the experimental cages placed over uninfested white-pine saplings near Ithaca. In the spring, before any weevils had been introduced, a female appeared, presumably from the litter at the base of the trees, and promptly began to oviposit. She laid 115 eggs in one shoot and did not move to any other during the entire period. The eggs proved fertile and nearly all of them hatched. No other weevil was in the cage during any part of the season; therefore, the only possible explanation is that either the weevils can reproduce parthenogenetically, or fertilization in this instance had taken place during the preceding year. The latter supposition seems, on the face of it, the more probable. Further evidence on this point is presented later in this paper.

After the brief period of feeding and mating, the females enter upon the task of oviposition. In ovipositing, the female makes with her beak a cavity in the bark of the terminal shoot, and excavates in the inner bark a chamber somewhat larger than the eggs she intends to lay. After carefully digging out and smoothing off the interior of this chamber, she turns around and feels about with her ovipositor until she finds the opening she has made. She deposits one, two, or occasionally three, of her small, pearly white, translucent eggs in the chamber. The operation of preparing the chamber and depositing the egg or eggs in it, often requires a half hour or more. The weevils continue ovipositing until sometime

in early July. The latest that oviposition has been observed in New York was on July 6. Eggs laid after July 1 are so few as to be a negligible quantity.

DEVELOPMENTAL STAGES

After a short period, which, depending on the temperature, varies from six to fourteen days, the eggs hatch and the tiny larvae burrow downward, first in the inner bark and then between the wood and the bark. They eat out all the soft inner bark and cambium as they advance. Many of these small larvae are smothered in the resin which is exuded by the tissues of the tree. The larva that works ahead of his brothers is at a distinct disadvantage, and is usually overwhelmed by resin and killed.

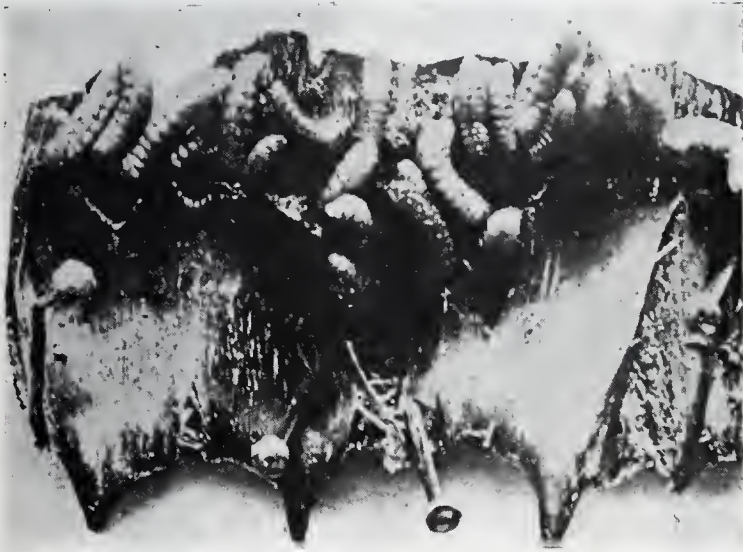


FIGURE 7. LARVAE OF THE WHITE-PINE WEEVIL, ALMOST FULL-GROWN

This illustrates how the larvae work side by side down the shoot

When, however, the larvae work in close formation, they kill the tissues of the tree so quickly that little resin is exuded. As a result of this, the larvae usually form a ring entirely around the stem and work downward, side by side.

When a larva that is a little older than his companions attains full size, he drops out of the line, burrows into the pith, turns upward, and forms a pupal cell. The remaining larvae work down the stem until each is fully grown. Sometimes, as has been mentioned previously, they pass below the second, or even the third, whorl of branches, thus making the total length of a single tunnel from eight to thirty inches. Occasionally, when they are crowded at a whorl, some of the larvae may work up the laterals and form in them their pupal cells. Frequently one finds more larvae attaining full growth at a given point than can be accommodated in the pith, and then the pupal chambers are formed in the solid wood or between the bark and the wood.

The pupal chambers made in the pith or the wood are merely cells hollowed out of the tissues, without any lining whatever. Those made beneath the bark, however, are of a different type. A hollow is made in the wood, and this is arched over with shreds of wood matted together, forming the chip cocoon which is described by Packard in his fifth report. In none of the infested shoots that have been cut open and examined



FIGURE 8. LARVAE AND PUPAE OF THE WHITE-PINE WEEVIL IN THEIR PUPAL CELLS



FIGURE 9. LARVAL TUNNELS OF THE WHITE-PINE WEEVIL

(and these number several thousand) has any lining been observed in the pupal chambers. Even those chambers that are roofed over with the chip cocoon have no lining on the side toward the wood.

The larva may remain in the pupal cell for two weeks before transforming to the pupal stage. This stage lasts about twelve days, when the transformation to the adult occurs. In 1915 the first pupae were observed on June 17, in shoots collected on May 9. If twelve days are added for the pupal period, fifty-one days were required from egg to adult under

conditions existing at Ithaca during the summer of 1915. This length of time would vary somewhat from season to season, since the length of the developmental period is influenced greatly by weather conditions.

ACTIVITIES OF THE YOUNG ADULTS

After the beetles transform, they remain in the pupal cells for a period of from two weeks to a month. Finally they gnaw their way to the outside. Emergence of the young adults continues from the middle of July through September and into October. After they emerge, the weevils feed for a short time on the newly formed buds or the young growth of pines. After this feeding period they seek a place in which to hibernate during the winter, although the weather at the time may still be warm.

Mention has already been made of an instance in which mating probably took place in the fall before hibernation. In order to determine whether or not this is possible, more than a hundred newly emerged weevils were placed in a cage in the laboratory on August 3. They were fed on fresh pine tips, which they ate voraciously at first. After a few days they became restless and began wandering around as if looking for a place in which to hibernate, but, since there was no litter in the cage, they were forced to keep in sight. They were kept in cages under observation until the last one died, in November. During this period but one pair copulated, and they only once. This indicates that occasionally the weevils may mate during the fall

in which they emerge, but that such mating is rare. Hopkins (1911) states that when the female weevils emerge their ovaries are undeveloped and they could not possibly produce eggs in less than a month after appearing as adults. If they laid eggs so late in the season as this would necessitate, the larvae would not be half grown by cold weather and could be found in the shoots during the winter. Never have living eggs, larvae, or pupae been found during the winter, although hundreds of infested shoots have been examined. One larva and one pupa, both in the pupal chamber, were found in the winter of 1914-15, but they were



FIGURE 10. WHITE-PINE WEEVIL ON A NEW SHOOT

both dead. Apparently they could not survive the cold weather. The larva of the parasite *Eurotoma pissodis* Gir. winters in the pupal cell of its host, and the confusion of this parasitic larva with the weevil may account for the statement repeatedly found in literature, that the weevil may pass the winter as a larva.

It seems possible that not all the adult weevils on the trees in mid-summer are adults that matured the preceding season. Possibly the beetles may live for two or three years and deposit eggs each year. From recorded observations of other species of the genus *Pissodes* in Europe and the United States, this fact has been definitely established (Hopkins, 1911). If this holds true for the white-pine weevil as well as for other species of the genus, then, if every immature individual should be wiped out of existence for one year or possibly two years in succession, there might still be enough adults the third year to reproduce the species and give it a fresh start. It may be due, in part, to its long life as adult, that the weevil is able to withstand the attacks of its enemies so well, winning out by persistence where other means might fail.

During the winter of 1914-15 the weevil was sought in hibernation, but without success. The method used in this search was to sift onto a white oilcloth the trash and litter that was taken from beneath the pines, and examine it carefully. The failure to find the weevil in this way was due, doubtless, to its close resemblance to the bits of trash in which it was hidden. In November, 1915, by the use of a modification of the Berlese trap, six adult weevils were found in the litter taken from under infested trees. On February 1, more litter from beneath the infested pines was examined by the same method and five more weevils were found. Therefore the statement can no longer be questioned, that the beetles hibernate in the litter beneath the infested trees.¹

A description of the trap, or extractor, used in finding these insects in hibernation, may be of interest. It consisted of an inverted cone, made of galvanized iron, with a one-inch opening at the bottom, where a detachable glass bottle was fastened. This cone was surrounded by a water jacket one inch thick. The water was kept warm by the application of heat to a tank at one side, the dimensions of which were 8 by 6 by 2 inches. The tank was connected to the water jacket by a half-inch pipe at the bottom and another at the top, thus providing for the circulation of the water. The legs were of wood and were attached to the water jacket by riveted hinges, so that they might be folded against the cone. A screen was placed about two-thirds of the way down the cone so that the material under examination might not drop to the bottom and clog the opening. The cone was then filled with litter.

In using this apparatus, the water in the jacket should be kept warm but not hot, so that the insects in the litter may be heated slowly. As soon as the insects become warm enough to come out of hibernation, they begin to work their way through the trash. Some burrow downward and fall into the bottle at the base of the cone. Others work their way upward and appear at the surface; these may be prevented from escaping by fastening a piece of cheesecloth over the top of the cone. So

¹ At the conclusion of this study of the life history of the white-pine weevil, it is evident that, of all the earlier workers, Hopkins (1907) has most accurately described the life cycle.

far, this apparatus has proved very useful in collecting all sorts of small and inconspicuous insects in hibernation which are easily overlooked in sifting litter.

CONTROL

The white-pine weevil, like other insects, can be controlled in several ways. The method to be selected depends on the conditions in each individual case. Control is largely an economic problem. The amount of labor and material used in these operations must be in proper proportion to the value of the trees protected. Naturally, the cost in all cases must be reduced to a minimum for the method used; but in some instances the value of the trees justifies the application of expensive control measures, whereas in other instances a comparatively low value of the trees will permit the application of only the indirect or preventive type of control. For example, white pines used in ornamental plantings have a high esthetic value that cannot be measured in dollars and cents. On the other hand, a forest whose only purpose is the production of wood can never be valued at more than the market price of the stumpage. Between these two extremes there are all gradations. In the first instance, a large expenditure would be justified; but in the second, only a small amount of labor and material can profitably be spent. In a timber forest, even a small, injudicious expenditure in the early years of the rotation may consume entirely the profit which the timber might have produced. In the following discussion of control, various methods are considered and the conditions under which each is applicable are pointed out.

Methods applicable in the control of the white-pine weevil may be divided into more or less arbitrary groups and subgroups, as follows:

- A. Direct control: Operations that deal directly with one or more stages of the insect, or with trees or parts of trees already infested. (Curative methods.)
 - 1. Chemical methods: Sprays; washes; repellents.
 - 2. Mechanical methods: Collecting adults; pruning shoots.
- B. Indirect control: Operations designed to modify environmental factors so that conditions become unfavorable for the rapid increase of the insect. (Preventive methods.)
 - 1. Silvicultural methods: Shading; dense planting.
 - 2. Biological methods: Parasites; predatory agents.

These groups are taken up in their proper sequence.

DIRECT CONTROL

The direct methods of control are in their very nature rather expensive, and are therefore limited in application to trees that have some value in addition to the wood produced. Only under unusually favorable conditions will growth be sufficiently rapid and stumpage prices sufficiently high to justify the application of these control methods in a timber forest.

Direct control is applicable to shade and ornamental trees in commercial nurseries, to windbreaks, along highways, on watersheds, and in some private forests where the esthetic value is an important consideration.

It is to be expected that not all methods of control are equally effective. In order to justify their use under any circumstances, direct methods must

be highly efficient in checking or preventing weevil injury. They must surpass in efficiency the indirect methods in proportion to the increased expense, or their use cannot be justified.

Chemical methods

It is doubtful whether the chemical method of applying sprays or washes will prove sufficiently effective in controlling this pest to make its use economically practical. Britton and Walden (1912), at the Connecticut Agricultural Experiment Station, have conducted a series of experiments testing various materials. They found lime-sulfur, 1 to 8, to be an effective repellent under certain conditions. Experiments with this material at Ithaca failed to give satisfactory control.

The results of insecticide tests conducted in the spring of 1916 are summarized in table 2. No safe and effective spray or wash has as yet been developed, with the possible exception of a spray of creosote or carbolineum.

TABLE 2. CHEMICAL EXPERIMENTS IN THE CONTROL OF THE WHITE-PINE WEEVIL, 1916

Material	Date of applica- tion	Method of appli- cation	Strength	Chemical injury	Number of trees treated	Number of trees weeviled
Kerosene emulsion.....	April 26	Painted	1 to 3.....	Considerable....	10	5
Creosote emulsion.....	April 13	Sprayed	1 to 2.....	None.....	10	3
Creosote.....	April 13	Painted	Pure.....	Trees badly in- jured.....	10	0
Carbolineum.....	April 13	Painted	Pure.....	Growth stopped.	10	0
Creosote.....	April 13	Sprayed	Pure.....	Very slight.....	10	0
Carbolineum.....	April 13	Sprayed	Pure.....	None.....	10	0
Soluble sulfur.....	April 26	Sprayed	4 lbs. to 100 gal.	None.....	10	4
Lime-sulfur.....	April 26	Sprayed	1 to 8.....	None.....	10	5
Scalecide.....	April 26	Sprayed	1 to 25.....	None.....	10	8
Powdered lead arsenate.....	May 6	Sprayed	3 lbs. to 50 gal.	None.....	10	3
Powdered lead arsenate.....	May 6	Sprayed	2 lbs. to 50 gal.	None.....	10	2
Paste lead arsenate.....	May 6	Sprayed	5 lbs. to 50 gal.	None.....	10	4
Paste lead arsenate.....	May 6	Sprayed	10 lbs. to 50 gal.	None.....	10	2
Calite.....	May 6	Sprayed	1 to 50.....	None.....	10	3
Calite.....	May 6	Sprayed	2 to 50.....	None.....	10	3
Carbolic emulsion.....	May 26	Sprayed	1 to 3.....	None.....	10	4

Check trees

Group no.	Number of trees	Number weeviled
1.....	30	8
2.....	6	2
3.....	10	3
4.....	10	5
5.....	10	4

Mechanical methods

Collecting adults

In Connecticut, Walden (1915) conducted a series of experiments to prove whether it is possible to control the white-pine weevil by collecting the adults during the period of oviposition. In those experiments a large net was held on one side of the terminal and a sharp blow was

administered on the other side, the beetles being thus knocked into the net. They were then removed from the net and killed. Undoubtedly an immense number of adult weevils can be captured in this way, but the question arises as to whether any appreciable impression on the numbers of the weevil can be made by this method in a badly infested plantation. Furthermore, the expense is too great for use in commercial plantations, since it costs from \$1.50 to \$2 per acre to make six collections. Felt (1906) also recommends this method of weevil control, and Peirson (1922) obtained satisfactory results by collecting adults in this way.

A method employed on the Clark estate near Cooperstown, New York, has combined the collecting of adults with the cutting and burning of the infested shoots. There are on this estate about sixty-five acres of white pines, which were planted in 1910. These trees were attacked when they were smaller than is ordinarily the case. At the time of the first attack, in 1915, and for a number of years thereafter, a fight was waged against the weevil. Two boys were employed at \$1.50 a day for practically three months of each year, barring rainy days. This made the cost of protection a little more than \$3 per acre, which would be prohibitive on a strictly commercial plantation. However, it was the belief of the forester in charge that this method was effective.

From experiments near Ithaca it was found that during the early part of the breeding season it was impossible to collect more than 75 per cent of the weevils by the net method, and at this time oviposition was going on at a most rapid rate. Small, badly infested plots were selected and were gone over with the net and stick. At this time the terminal cluster of buds had not separated. The weevils hide in the terminal bud cluster, and, when shaken, wedge themselves between the buds. Those that were resting on the stem could easily be knocked off into the net, but those hidden among the buds wedged themselves in so tightly that, in spite of the hardest shaking and knocking, they were not dislodged. After a plot had been covered with the net, each shoot was examined very carefully, and in every plot a considerable number of weevils were found hidden among the buds. In one case there were more weevils left in these bud clusters than were caught in the net. Undoubtedly a number of weevils, when shaken off, missed the net and afterward found their way back to another terminal. After the bud cluster had separated, however, exceedingly good results were obtained by this method. It was impossible to tell just what percentage of the weevils were captured, but, judging from the small number to be found in the plots a day after the collecting, the proportion caught was high. From this it would appear that during the first of the season, collecting with a net is of little value though after the separation of the bud clusters it is satisfactory so far as the number of insects caught is concerned; but unless it is used in combination with some other method, such as pruning the weeviled shoots, its efficiency is doubtful.

Pruning shoots

The most practical and economical of the mechanical methods brought to the writer's attention, seems to be that of removing and destroying infested shoots before the emergence of the weevils. Even this method is too expensive and uncertain for general use in timber plantations. How-

ever, the practice has been advised by almost all the investigators who have studied the white-pine weevil, and, although it is rather expensive, it is reasonably effective if the work is done carefully and on a sufficiently extensive scale. The best time for such pruning, if it is possible to go over the plantation only once during the season, is the first half of the month of July. At this time practically all of the infested shoots have begun at least to wilt, and most of them have turned brown. They are then very conspicuous. The work can be carried on rapidly in a plantation where the trees are set out regularly. In irregular natural reproduction, it goes forward much more slowly and is correspondingly more expensive. If possible, it is better to remove the infested leaders twice during the year: once in the month of June, and again in August. Before July few of the weevils will have worked below the first whorl of branches; and if the shoots are removed before that time, the leader will come from this whorl and a whole year of height growth will not be lost. Also, the laterals in this topmost whorl, because of their small diameter, are capable of straightening up much more easily than are the larger branches of the lower whorls. In July many larvae pass below the first whorl, and sometimes by the end of that month, the second, and in a few cases the third, whorl has been passed. This results in a much more serious loss in height growth, and causes a crook that may never grow out. In June it is difficult to get all of the infested shoots, as some, in which the eggs have been recently laid, are rather inconspicuous; and so, in order to get those that have been missed, a second cleaning in August is advisable.

The infested shoots should be removed every year as long as the weevils are in sufficient numbers to endanger the final stand. This is especially true if the infestation is concentrated in spots, as is often the case. The weevils, as has already been mentioned, may perhaps live for as long as three years and deposit eggs each year. If this is the case, it will be necessary to prune for at least three years in succession, in order to suppress an outbreak. If there are any other infested trees near by, they should be treated in order to reduce the number of weevils flying into the plantation from outside. By this method the weevil can be kept within reasonable limits.

All infested shoots pruned from the trees should be disposed of in such a way as to make certain that the weevils do not get back to the trees. If a shoot is cut off and left lying on the ground, the weevils will go through their transformations and emerge just as if the shoot had been left on the tree. Therefore such shoots must be disposed of in some way. The method usually employed is that of burning the shoots. This certainly kills the weevils, but it also destroys the parasites and some of the predacious insects that prey upon the pest. Naturally the destruction of these beneficial forms of life is not to be desired. A much better plan is to place the infested shoots in receptacles tightly covered with wire mosquito netting. The wire netting should be no coarser than sixteen meshes to the inch. The weevils will be unable to escape, but most of the parasites can easily make their way through the meshes. Any tight receptacle will answer. It should not be stood upright, as in that position it would collect rain. The containers should not be opened, but should be left in the plantation until the following spring, when all the parasites will have emerged. By that time the weevils should all be dead, since the

containers offer neither food nor a suitable place in which they could hibernate.

Removal of the infested shoots suffices to keep the weevil in check, but it does not help the trees to recover from the attack. The laterals compete for the leadership, just as if the dead leader were still on the tree, and the characteristic forks and crooks result. If the trees are pruned in such a way as to favor one of these laterals as leader, they will be able to outgrow the weevil injury much more rapidly than would otherwise be the case. Experiments made in the course of the work show that, where the expenditure is possible, the pruning of all but one lateral in the top-most living whorl gives the best results.

INDIRECT CONTROL

In commercial forests, where the value of the trees must be measured in terms of the wood produced, it is essential that the cost of controlling tree insects be kept at the minimum. This is particularly true during the early years of the rotation, when even a small injudicious expenditure means a considerable loss. It is under such conditions that one must rely almost entirely on the indirect methods of control.

Silvicultural methods

It has been the observation of all who have made any study of the injury done by the white-pine weevil that this insect shows a decided preference for trees growing under certain conditions. If this holds consistently true, then one method of indirect control would be to secure for the growing of white pine those silvicultural conditions which are least conducive to weevil injury. In order to ascertain just what would be the best conditions to maintain, a series of experiments was carried on in New York and in Minnesota by means of sample plots laid out under as wide a variety of conditions as could be found.

These sample plots were, for the most part, one-tenth acre in area, although in some cases they contained only one-sixteenth of an acre. In a few instances larger plots were used. By using small plots it was possible to so place them that conditions were fairly uniform throughout a plot, which with plots of larger size would have been difficult if not impossible. Practically all the plots were in stands resulting from natural reproduction.

In these plots the relation of weevil injury to density, rate of growth, age, forest composition, and other factors, was studied with the object of determining what conditions would secure for white pine the greatest immunity from the weevil. The purpose of the experiments was to obtain data sufficiently conclusive to warrant the recommendation of certain definite silvicultural methods that would eliminate, or at least materially reduce, the weevil injury. This aim has been attained; and the correctness of the conclusions drawn from the data collected in this phase of the work have been verified by later investigators.

It has already been noted that under certain conditions the weevil is particularly abundant — for example, on young trees from five to twenty years old, and trees that are growing unusually rapidly. These two conditions are not of particular interest in the control phase of the work,

because their very nature precludes their being changed. It is obvious that all trees must pass through the susceptible age before being marketed, and that rapid growth is in itself a commercial asset. These investigations have, however, brought to light other silvicultural conditions favorable to the weevil, which can be so changed as to reduce the amount of injury, in some cases even to the point of almost complete elimination.

Shading

All students of the white-pine weevil have noticed the insect's preference for trees exposed to the sunlight, and the present experiments have confirmed this observation. Weevil injury is invariably greatest in open pure stands of white pine growing in full sunlight. In mixed stands where hardwoods shade the pine, the injury is much less, and it decreases with increasing intensity of shade until it reaches the zero point under a shade such as that cast by an average stand of oak or maple.

In view of these facts, which have been proved beyond a doubt, it would seem that some system of silviculture should be used which would provide shade during the susceptible period: that is, until the trees are about fifteen to twenty-five years of age or somewhere between twenty and thirty feet in height. The density of shade tolerated by white pine will vary with soil and moisture conditions, and therefore must be determined separately for each site. On the better soils in New York, and to a lesser degree in the Lake States, white pine reproduces itself well under the shade of mixed pine and hardwoods. It would, however, be necessary to liberate the young pines by means of thinning, in order to prevent their succumbing to the competition of the overtopping trees. On poorer soils it would be difficult, if not impossible, to grow pines under hardwoods.

Peirson (1922), as a result of experiments conducted in Massachusetts, also advises the growth of white pine in mixture with hardwoods in such a way that the pine will be slightly overtopped until it has reached the age of about fifteen years. In view of the fact that his experiments were carried on without knowledge of the work done around Ithaca or in Minnesota, it would appear that shading has received double recommendation as a silvicultural method of control.

Dense planting

The question next arises as to whether it is possible to protect pine from the weevil where shading is not feasible, such as in pure stands of volunteer young pine in old pastures, and in white-pine plantations. The answer to this question was found in data gathered from the sample plots of experiments regarding the influence on weevil injury of density of stand. From these experiments it appeared that in open stands where the crowns are all free, the trees are all equally subject to attack, but in the denser stands the percentage of trees that are attractive to the weevil is much less. In very dense stands the injury caused by this insect may be reduced to almost nothing.

The effect of the original density of the stand upon its susceptibility to weevil attack is illustrated in figure 11. The curve indicating the percentage of trees that show the effect of weevil injury at thirty years is a summary of data collected in Minnesota, and represents an average of all plots where the original density could be determined with reasonable

accuracy. The other curves in the figure are from data collected on the Luther Forest Preserve in New York State.

From these curves it is evident that the percentage of trees attacked by the weevil decreases with an increase of density. But, important as

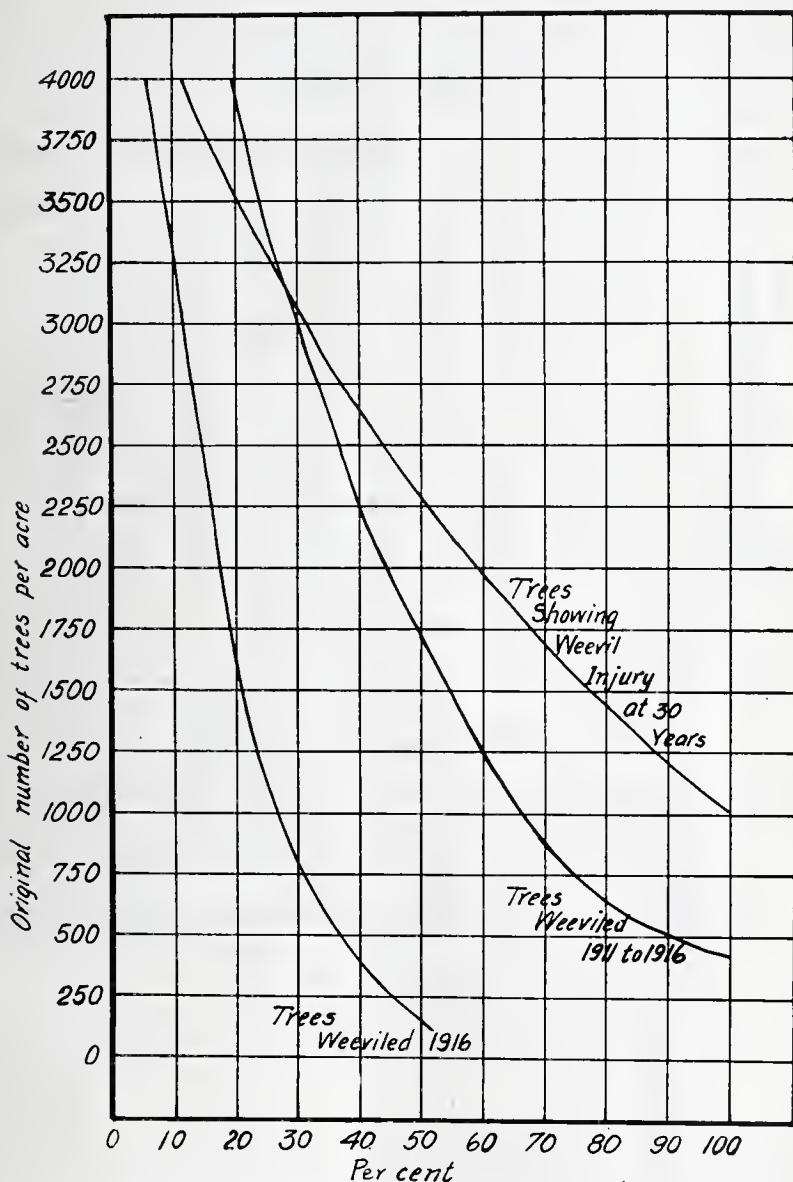


FIGURE 11. EFFECT OF ORIGINAL DENSITY ON SUSCEPTIBILITY TO WEEVIL ATTACK

this fact may be, it is overshadowed by the influence of density on the ability of the trees to outgrow weevil injury. In the open, a tree has no competition from the sides and therefore the stimulation to straight growth is slight. White pines growing in the open, practically never outgrow weevil injury. They almost invariably become forked and

crooked. On the other hand, when a tree is growing in a closed stand, competition for light and space stimulates it to straight growth. The denser the stand, the greater is the competition and the greater is this stimulus to straight growth. As a result of this competition, trees growing in a dense stand are much better able to straighten and to outgrow the injury caused by the weevil attacks, and thereby to become merchantable. The percentage of unmerchantable trees bears a direct relation to the original stand density, as is indicated in figure 12, which shows the pro-

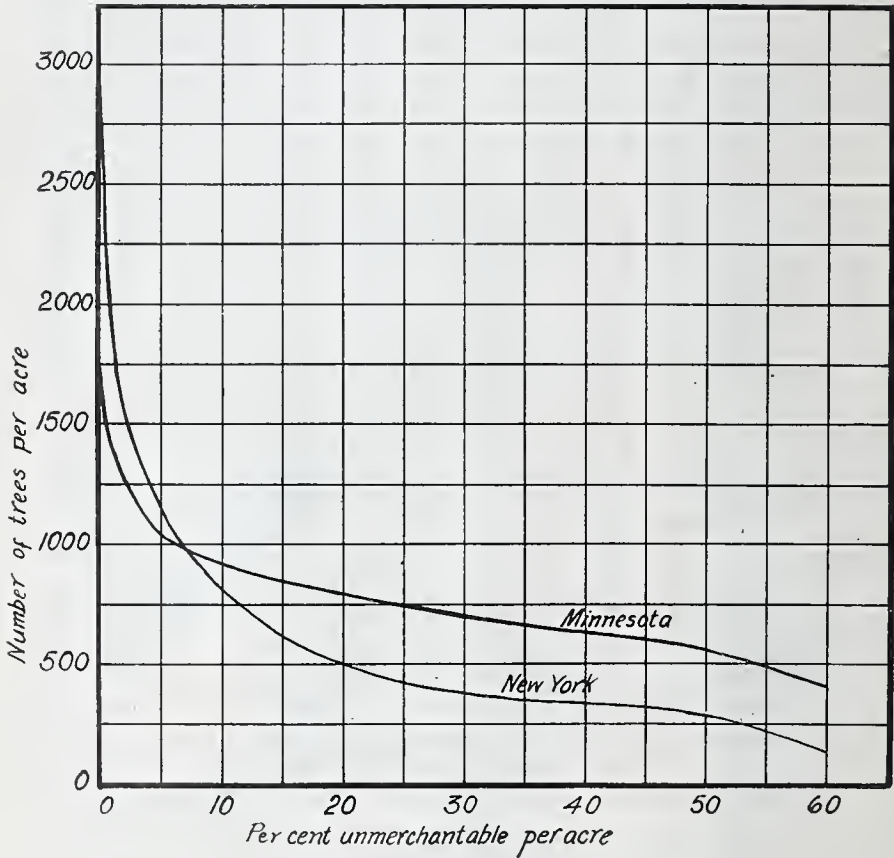


FIGURE 12. PER CENT OF UNMERCHANTABLE TREES PER ACRE WITH DIFFERENT ORIGINAL DENSITIES

portion of unmerchantable trees that may be expected at the age of thirty years at different densities. It is interesting to note that the curves for New York and Minnesota are fairly similar in spite of the climatic differences existing between the two localities.

On comparing figures 11 and 12, it will be noted that in fully stocked stands the proportion of weeviled trees that actually become unmerchantable is comparatively small. Where there is a strong stimulus to straight growth, almost all the weeviled trees succeed in outgrowing the injury. At a density of 1200 trees per acre, only a few trees are likely to be unmerchantable. At an original density of 1500 trees per acre, a fully stocked stand of straight merchantable trees is practically assured.

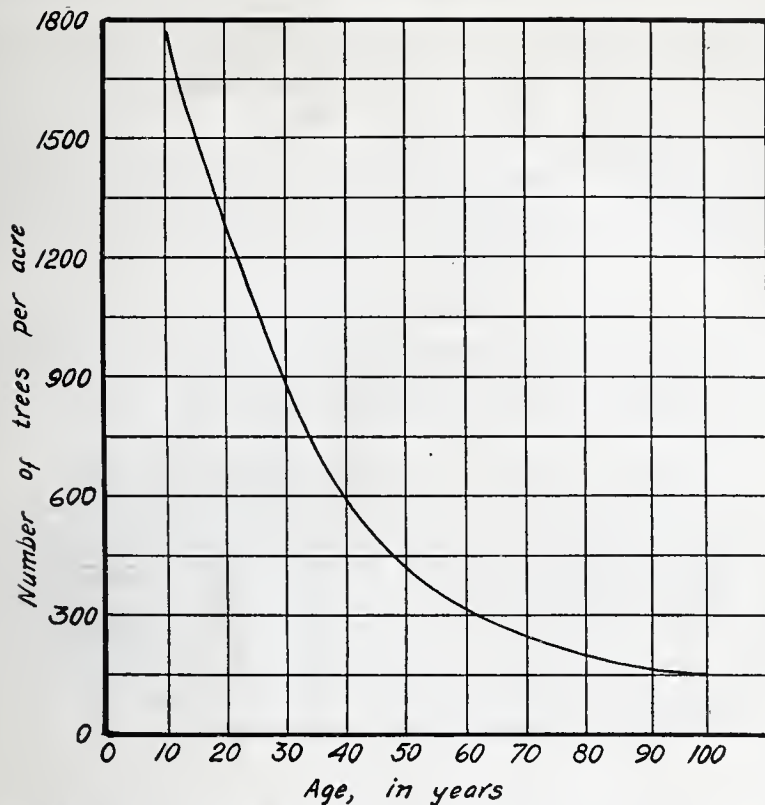


FIGURE 13. NUMBER OF TREES PER ACRE IN A FULLY STOCKED STAND OF WHITE PINE AT DIFFERENT AGES

The reduction in number is due to the natural thinning that results from competition
(After Hawley, *Practice of Silviculture*)

From these data it is apparent that if a density of from 1200 to 1500 trees per acre is maintained throughout the early years of the rotation, and a fully stocked stand thereafter (figure 13), then the loss resulting from the attack of the white-pine weevil will be at a minimum. On the other hand, if a fully stocked stand is not maintained, a serious loss may be expected. This conclusion has been independently verified by Peirson (1922), so that the facts of the case appear to be well established.

From the foregoing discussion it is evident that there are two possible courses of silvicultural procedure that may be followed for protection of white pine from the weevil. In mixed forests on good soil, this tree can be grown



FIGURE 14. TREE IN DENSE STAND OUTGROWING WHITE-PINE-WEEVIL INJURY

The leader was killed by weevils, and the lateral gained the lead and formed a nearly straight trunk. The remnant of the leader still projects from the side of the trunk

as an "under-story" until a height of from twenty to thirty feet has been attained. The shade should, however, be kept sufficiently light to permit good growth. In pure stands, the keynote of weevil control is a fully stocked stand. Open natural stands should have at least 1200 trees per acre, and, wherever possible, 1500 per acre. A density of at least 1200 trees per acre should be maintained until the trees are somewhere between twenty and twenty-five years old.

Biological methods

Control of insect pests by means of parasites and predatory agents is always an attractive possibility. Too often, however, closer investigation brings disappointment, particularly with native pests such as the white-pine weevil.

If it were possible to breed and liberate parasites in such large numbers as to be an effective control for this insect, or if the activities of predatory agents could be regulated, the problem of weevil control might be much simplified. Such regulation, however, is impossible, at least at the present time. Nevertheless these biological elements play an important part in reducing the numbers of the weevil. If it were not for parasites, predatory agents, and occasionally adverse weather conditions, this insect would be a much more serious menace to our white-pine plantations than it is. Therefore they cannot be disregarded.

Parasites

During the course of these investigations a record was kept of the activities of insect parasites of the white-pine weevil. The most abundant, both in New York and in the Lake States, is *Eurytoma pissodis* Gir. In addition to this parasite, three unidentified chalcids and two braconids have been reared. These, however, have been found in such small numbers as to be an almost negligible quantity so far as their value in controlling the weevil is concerned. It seems probable that they are more or less accidental parasites, and ordinarily find their host in some other insect; or that they are more or less general parasites, and therefore attack a number of other species of insects.

Peirson (1922) reared parasites of the white-pine weevil belonging to the genera *Epirus*, *Eurytoma*, *Microbracon*, and "apparently *Paracrias*." A number of other occasional parasites have been reared by various workers.

In the vicinity of Ithaca, *Eurytoma pissodis* Gir. is by far the most important parasite of the weevil. In several pine clumps the weevils were found to be parasitized to the extent of 50 per cent. A similar degree of parasitism by this species seems to hold consistently wherever the white-pine weevil is abundant. During the month of July the adult parasites were abundant among the infested pines, ovipositing on the larvae of the weevil. The eggs were not observed, but apparently they are deposited in the pupal cells of the weevil since the larvae feed externally upon their host and have been found only in these cells. When fully grown, the larvae of this parasite are only a little smaller than the weevil pupa. They pass the winter in the pupal cells of their host, and in the early spring they pupate and transform to the adult. The whereabouts

of this parasite during May and June is unknown. Perhaps another generation develops on an alternate host.

Predatory agents

In spite of its parasites, the weevil succeeds in maintaining itself. But these are not the only enemies it must face, for there are a number of predacious insects that prey upon it. Packard (1885) states that the young beetles of the family Tenebrionidae are very commonly predacious on the larvae of the white-pine weevil. In the course of this study none of these beetles have been observed at this work, but the adults of this family are very common about young pines. Larvae of the clerid beetles, however, have been found in the weeviled shoots, evidently feeding on the larvae of *Pissodes*, and one of these was successfully reared and identified as *Elasmoserus terminatus*.

The most important predacious insect that has been observed in this study is the larva of a fly which is not ordinarily considered as predacious, *Lonchaea rufatarsus*. The larvae of this species are universally present in shoots infested by the white-pine weevil, and, when confined with the weevil larvae, have been observed to feed upon them. Usually several will attack one larva at the same time and will devour it quickly. They feed upon the pupae also, to some extent.

In addition to insects, there are predacious mammals and birds which feed to a greater or less extent upon the weevil in its various stages. Undoubtedly, as compared with the birds, the mammals are of little account in this work; but in the pine thickets there are found several small mammals, the food of which consists to a greater or less degree of insects. The short-tailed shrew is very common in such places, and lives entirely on insects. During the months when the weevils are in or on the ground, particularly at the seasons when they are emerging from or entering hibernation, the shrews have an excellent opportunity to feed upon them. Practically all of our field and wood mice are very fond of insects of any kind — several of these animals, which were being kept in a cage, preferred them to grain — and so it seems likely that some weevils fall victims to these small rodents.

Of all the vertebrates, however, the birds are undoubtedly the greatest enemies of the weevil. It is more or less common, in infested patches, to find some of the infested shoots cleaned out by birds, although no birds have been observed in the act. Of our common birds, the most likely to do this work are the nuthatches, the chickadees, and the downy woodpeckers. Unfortunately, these birds continue to work on the dead shoots throughout the winter, when only the parasites are present, and thus undo a part of the good work that was begun in the summer. The pine thickets are a favorite place throughout the entire year for many of our birds, and undoubtedly they feed upon the adult weevils to some extent at least. In the spring and fall, when the weevils are entering and leaving the ground, they lay themselves open to the attack of the ground feeders, such as the chewinks, the thrashers, the grouse, and the quail. The chipping sparrows and the wrens are abundant in all white-pine thickets, and probably eat some of the weevils.

Domestic fowl may be of value in controlling the weevil in small plantations. Chickens and turkeys have been used in the South, with marked

success in some cases, to aid in the control of the closely related cotton-boll weevil; and in one instance in New York, the white-pine weevil has been at least partially checked by allowing chickens to run in the plantation.

SUMMARY

The white-pine weevil is one of the most dangerous and destructive pests of young white pine and Norway spruce. It attacks and kills the leading shoots of large seedlings and small saplings. Not only does this injury result in a loss in the rate of height growth, but in many cases it is the cause of serious crooks and forks in the main stem of the tree. In many instances, trees are rendered commercially valueless by the injury.

This weevil has but one generation a year. The adults appear on the trees in the early spring, after having hibernated over winter in the litter beneath the trees. They deposit their eggs in the leading shoots, and the larvae, when hatched, work downward as they feed upon the inner bark. Thus the shoot is girdled and killed. The injury frequently extends below the topmost whorl of laterals, and sometimes below even the third whorl from the top. After completing their growth, the larvae excavate pupal cells in the pith or the wood, transform to the pupal stage, and emerge as adults in August and September. After feeding for a short time on the new growth and buds of the pines, the young adults retire to their winter quarters in the litter beneath the trees.

A number of effective methods for the control of the white-pine weevil have been developed. They may be divided into two main groups, direct methods and indirect methods. In the first group are included all of those methods that deal directly with one or more stages of the insect, or with trees or parts of trees already infested. In the second group are included all operations designed to modify environmental factors so that conditions become unfavorable for the rapid increase of the weevil. The direct methods are expensive, and are applicable only in shade and ornamental plantings, along highways, on some watersheds, and in some private forests where the esthetic value is an important consideration. In the timber forest, only the indirect methods can be used except under very unusual circumstances.

Of the direct methods that have been developed for the control of this insect, the most effective is a combination of collecting adults in the spring, and pruning injured leaders in the summer. The best method of collecting adults is to jar the beetles from the trees into a net held beneath them. Pruning of injured leaders should be done in June and again in August, or, if only one treatment is to be given, in July. Pruning all but one lateral tends to stimulate recovery and is a desirable operation when possible.

Sprays and washes have been recommended for the control of the white-pine weevil, but they have not proved sufficiently effective to warrant their use.

In timber forests, one of two practical methods of indirect control can be used. In established forests on good soil, white pine should be grown under a form of the shelter-wood system that will provide a light shade for the young trees until they have reached a height of from twenty to thirty feet. The shade should not, however, be sufficiently heavy to seriously interfere with the growth of the trees.

On the poorer soils, in plantations, and in volunteer growth in old fields where even-aged pure stands cannot be avoided, another method for weevil control is effective. It has already been shown that density is an important factor in determining both the abundance of the weevil and the amount of injury resulting from its attack upon the trees. With an original density of 1500 trees per acre, very little weevil injury will be evident at the end of the rotation. Even at the standard density of 1200 trees per acre, comparatively little injury will result if a fully stocked stand is maintained throughout the first thirty years after planting. This is due in part to a reduction in the amount of weeviling, but in a much greater measure to the effect of competition in stimulating straight growth.

Parasites and predatory agents play an important part in the natural control of this insect. The most abundant and effective parasite throughout the range of the weevil is *Eurytoma pissodis* Gir. In some cases more than 50 per cent of the weevil larvae are parasitized by this species. Predatory insects and vertebrates are important aids in reducing the numbers of the weevil.

In view of the facts brought to light by the experiments in both New York and Minnesota, it seems safe to say that the young white pine needs no longer to be seriously menaced by the white-pine weevil, because the insect can be controlled under any condition in which a fully stocked stand can be maintained throughout the first twenty-five or thirty years of the rotation, or where white pine can be grown under the shelter-wood system or some other system that will provide shade for the sapling pines. This means that where good silvicultural methods are in force, this pest can be effectively and economically controlled.

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